REPEAT CT BRAIN IN MILD TRAUMATIC BRAIN INJURY WITH INTRACEREBRAL HEMORRHAGE

Bikram Shakya, Bidur KC

Department of Neurosurgery, Kathmandu Medical College Teaching Hospital, Sinamangal, Kathmandu, Nepal

ABSTRACT

Traumatic brain injury (TBI) is a significant public health concern, and the role of repeat computed tomography (CT) scans in managing TBI remains a critical area of investigation. This study evaluates the utility of repeat CT scans in detecting clinically significant changes that necessitate intervention and impact patient outcomes. The aim of this prospective study was to assess the clinical value of repeat CT scans in TBI patients by analyzing patient demographics, initial and repeat CT findings, surgical interventions, and short-term outcomes. The study included 200 patients with TBI who underwent both initial and repeat CT scans at Kathmandu Medical College Teaching Hospital between January 2022 and December 2023. The mean age of the cohort was 45.3 ± 18.6 years, with a male predominance (70%). The initial Glasgow Coma Scale (GCS) scores categorized 65% of patients with mild TBI (GCS 13-15), 25% with moderate TBI (GCS 9-12), and 10% with severe TBI (GCS ≤8). Repeat CT scans were performed based on clinical indications such as deterioration, new symptoms, or for routine follow-up. Statistical analyses included paired t-tests, chi-square tests, and logistic regression, with significance defined as $p < 0.05$. The initial CT scans revealed intracranial hemorrhages in 60% of patients, with subdural hematomas being the most common (40%). Repeat CT scans identified new or worsening hemorrhages in 30% of patients, leading to surgical intervention in 25%, primarily through hematoma evacuation (60%) and decompressive craniectomy (40%). Paired t-tests demonstrated a statistically significant difference between initial and repeat CT findings ($p <0.01$). Chi-square tests indicated a significant association between clinical deterioration and the need for repeat CT ($p <0.05$). Logistic regression analysis identified the initial GCS score (OR: 2.5, 95% CI: 1.5-4.1), type of hemorrhage (OR: 1.8, 95% CI: 1.2-2.9), and the presence of skull fractures (OR: 2.2, 95% CI: 1.3-3.7) as predictors of surgical intervention following repeat CT scans. This study underscores the importance of repeat CT scans in TBI management, particularly for patients with severe injuries or clinical deterioration, where it influences surgical decisions and patient outcomes. The findings advocate for a selective imaging approach, optimizing resource use while ensuring patient safety.

KEYWORDS

Clinical outcomes, Glasgow coma scale, intracranial hemorrhage, repeat CT

***Received on**: August 22, 2024*
***Accepted for publication**: October 28, 2024*

CORRESPONDING AUTHOR

Dr. Bikram Shakya
Associate Professor,
Department of Neurosurgery,
Kathmandu Medical College Teaching Hospital
Sinamangal, Kathmandu, Nepal
Email: drsbikram@gmail.com
Orcid No: https://orcid.org/0000-0002-9338-0510
DOI: https://doi.org/10.3126/nmcj.v26i4.74458

INTRODUCTION

Traumatic brain injury (TBI) is a significant public health issue, with over 50 million cases reported annually worldwide, making it one of the major traumatic diseases threatening human health.[1] In 2018, TBI was referred to as a "silent epidemic" in a paper published in the Journal of Neurosurgery, with estimates indicating 64 to 74 million new TBIs reported each year.[2] Road traffic accidents have been identified as the leading risk factor for TBI, particularly prevalent in Southeast Asian and African nations.[3]

Mild traumatic brain injury (MTBI) accounts for the majority of TBIs, representing approximately 80% of cases.[4] A significant subset of MTBI patients presents with intracerebral hemorrhage (ICH), which poses a complex clinical scenario due to the potentially dynamic nature of these injuries.[5] The initial computed tomography (CT) scan is a critical diagnostic tool for assessing the extent of injury and guiding immediate interventions. However, the necessity and optimal timing of subsequent CT brain scans remain subjects of debate.[6] Factors influencing the decision to repeat imaging include concerns for hematoma expansion, changes in neurological status, and clinical deterioration.[7]

The use of head CT scans is standard in the management of TBI patients due to its ability to rapidly and accurately detect intracranial hemorrhage, and it is frequently included in the general multi-trauma work-up.[8] Despite this, there is significant variability in the practice of repeating head CTs among neurosurgeons, influenced by regional practices and individual clinical judgment.[9] The clinical decision-making process for repeat CT imaging is crucial, particularly for patients with neurological deterioration, defined as a decrease in the Glasgow Coma Scale (GCS) score by ≥2, changes in pupillary size, or the onset of symptoms indicative of increased intracranial pressure (ICP).[10] For MTBI patients without neurological deterioration, the value of repeat head CTs in predicting the need for intervention is limited.[11] Studies have shown no significant difference in the intervention rate between patients whose CT brain scans were repeated due to neurological deterioration and those without.[12]

In addition to clinical considerations, the economic implications of repeat imaging are substantial. The financial impact of repeat CT scans, coupled with the potential benefits to patient care and outcomes, underscores the importance of a comprehensive analysis.[13] Reducing unnecessary repeat CT scans could result in lower hospital costs, decreased radiation exposure for patients and staff, and reduced length of hospital stays, without compromising patient safety.[14]

Understanding the clinical role of repeat CT brain scans in mild TBI with ICH is pivotal not only for healthcare providers but also for the well-being of affected individuals. This study aims to assess the necessity and timing of repeat CT brain scans, their impact on patient management decisions, and their influence on patient outcomes, including length of hospital stay and mortality. The knowledge generated by this research may contribute to improved patient care, informed clinical decision-making, and the optimization of healthcare resources.

The primary aim of this prospective study is to evaluate the utility and outcomes of repeat CT scans in patients with TBI at Kathmandu Medical College Teaching Hospital (KMCTH), Sinamangal, Kathmandu, Nepal. The study seeks to determine the clinical indicators prompting repeat CT scans by identifying the most common symptoms and signs leading to such decisions. It also aims to assess the findings of repeat CT scans by comparing them with initial scans to identify any changes such as new hemorrhages, progression of existing hemorrhages, or other intracranial abnormalities. Furthermore, the study evaluates the interventions based on repeat CT scan findings, determining the proportion of patients requiring surgical intervention versus conservative management. Additionally, it analyzes the short-term neurological outcomes and prognosis of patients undergoing repeat CT scans, including length of hospital stay, need for intensive care, and functional status at discharge. The study also aims to identify clinical and radiological predictors that necessitate surgical intervention following repeat CT scans through logistic regression analysis. While this study does not directly evaluate the cost-effectiveness of repeat CT scans, it highlights the importance of future research in this area to develop evidence-based guidelines for optimizing patient care and healthcare resource allocation in TBI management.

MATERIALS AND METHODS

This prospective study was conducted at KMCTH, Sinamangal, Kathmandu, Nepal; from January 2022 to December 2023. The study aimed to evaluate the utility and outcomes of repeat CT scans in patients with traumatic brain injury (TBI).

Patients of all ages presenting to the emergency department with TBI who underwent an initial CT scan followed by at least one repeat CT scan during their hospital stay were included in the study. Exclusion criteria were patients with non-traumatic brain injuries, those who did not undergo repeat CT scans, and those with incomplete medical records.

Based on previous studies and a pilot analysis, a sample size of 200 patients was estimated to achieve sufficient power to detect significant differences in clinical outcomes and radiological findings between initial and repeat CT scans. Data were collected prospectively from patient medical records and imaging databases.

Data were analyzed using SPSS-20. Descriptive statistics were used to summarize patient demographics, clinical presentation, and CT scan findings. Continuous variables were presented as mean ± standard deviation, while categorical variables were presented as frequencies and percentages. Comparative analysis between initial and repeat CT scan findings was performed using paired t-tests for continuous variables and chi-square tests for categorical variables. Logistic regression analysis was conducted to identify clinical and radiological predictors of surgical intervention following repeat CT scans. The significance level was set at $p < 0.05$.

The study was approved by the Institutional Review Committee of Kathmandu Medical College Teaching Hospital. Informed consent was obtained from all patients or their legal guardians before inclusion in the study. Patient confidentiality was maintained throughout the study.

RESULTS

A total of 200 patients with traumatic brain injury (TBI) who underwent initial and repeat CT scans were included in the study (Table 1; Fig. 1, Fig. 2 and Fig. 3). The mean age of the patients was 45.3 ± 18.6 years, with a male predominance (70%). The majority of patients presented with a GCS score of 13-15 (65%), followed by moderate TBI (GCS 9-12; 25%) and severe TBI (GCS ≤ 8; 10%). Common symptoms at presentation included headache (60%), vomiting (45%), and neurological deficits (30%).

Initial CT Scan Findings: The initial CT scans (Table 2) revealed intracranial hemorrhage in 120 patients (60%), skull fractures in 80 patients (40%), and other intracranial abnormalities such as contusions or edema in 60 patients (30%). The types of hemorrhage included

Table 1: Patient demographics and clinical presentation

Characteristic	Value
Total number of patients	200
Mean age (years)	45.3 ± 18.6
Gender	
- Male	140 (70%)
- Female	60 (30%)
Initial GCS Score	
- 13-15 (Mild TBI)	130 (65%)
- 9-12 (Moderate TBI)	50 (25%)
- ≤ 8 (Severe TBI)	20 (10%)
Presenting Symptoms	
- Headache	120 (60%)
- Vomiting	90 (45%)
- Neurological deficits	60 (30%)

Table 2: Initial CT scan findings

Findings	n (%)
Intracranial hemorrhage	120 (60%)
- Subdural hematoma	80 (40%)
- Epidural hematoma	60 (30%)
- Intracerebral hemorrhage	60 (30%)
Skull fractures	80 (40%)
Other intracranial abnormalities	60 (30%)

Table 3: Indications for repeat CT scans

Indications	n (%)
Clinical deterioration	100 (50%)
New symptoms	60 (30%)
Confirmation of complications	40 (20%)
Routine follow-up	50 (25%)

Table 4: Repeat CT scan findings

Findings	n (%)
Progression/new hemorrhage	60 (30%)
- Subdural hematoma	27 (45%)
- Epidural hematoma	21 (35%)
- Intracerebral hemorrhage	12 (20%)
Stability of initial findings	100 (50%)
Resolution of abnormalities	40 (20%)

Table 5: Interventions based on repeat CT findings

Intervention	n (%)
Surgical intervention	50 (25%)
- Decompressive craniectomy	20 (40%)
- Hematoma evacuation	30 (60%)
Conservative management	150 (75%)

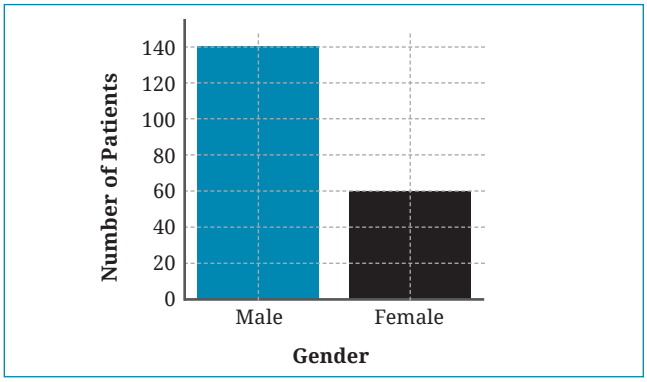

Fig. 1: Patient gender distribution

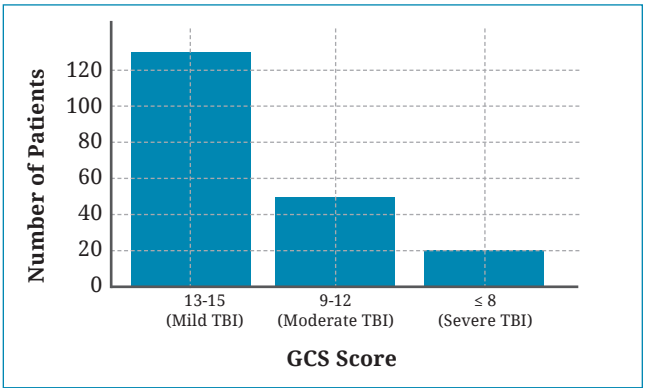

Fig. 2: Initial GCS score distribution

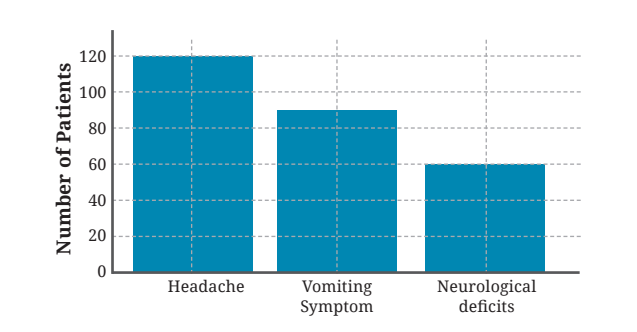

Fig. 3: Presenting symptoms

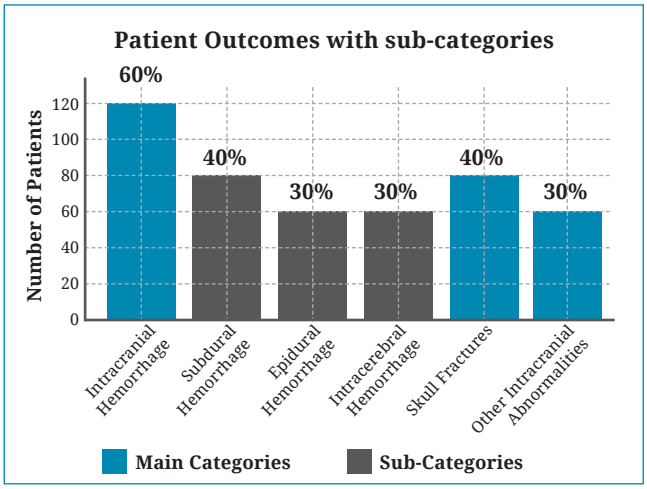

Fig. 4: Initial CT scan findings

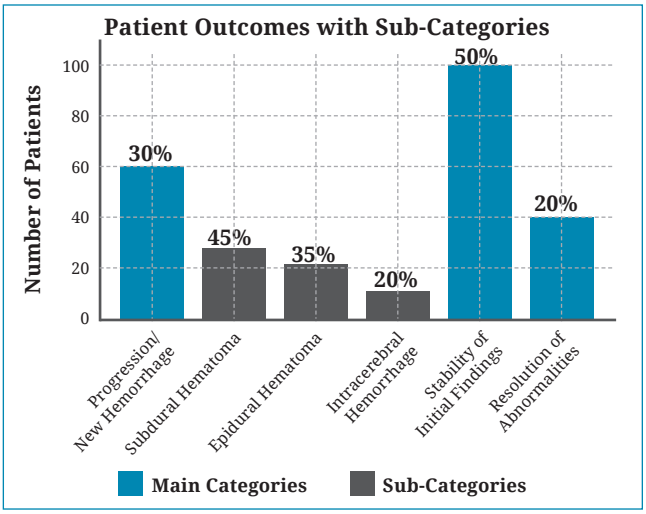

Fig. 5: Repeat CT Scan Findings

subdural hematoma (40%), epidural hematoma (30%), and intracerebral hemorrhage (30%).

Repeat CT scans were performed based on clinical indications in 150 patients (75%) and as part of routine follow-up in 50 patients (25%). Clinical indications included clinical deterioration (50%), new symptoms (30%), and confirmation of suspected complications (20%).

Repeat CT Scan Findings: Repeat CT scans showed progression or new hemorrhage in 60 patients (30%), stability of the initial findings in 100 patients (50%), and resolution of abnormalities in 40 patients (20%). Among the patients with progression or new hemorrhage, subdural hematoma was the most common type (45%), followed by epidural hematoma (35%) and intracerebral hemorrhage (20%).

CT scans were repeated in patients with initially normal CT scans when clinically indicated, particularly in cases of clinical deterioration, new symptoms, or for routine follow-up. Of the 80 patients with normal initial CT scans, repeat CT was performed in 30 patients (37.5%) due to clinical indications such as clinical deterioration or new symptoms, and in 15 patients (18.75%) as part of routine follow-up. 12 patients (15%) showed new abnormalities on repeat CT, which included new intracranial hemorrhages or progression of undetected lesions such as contusions or edema. This underscores the potential importance of repeat CT even in cases where the initial scan was normal, especially in the presence of new or worsening clinical symptoms.

In 25% of the patients (50 out of 200), repeat CT scans led to changes in management, particularly the decision to perform surgical interventions such as hematoma evacuation or decompressive craniectomy. For patients

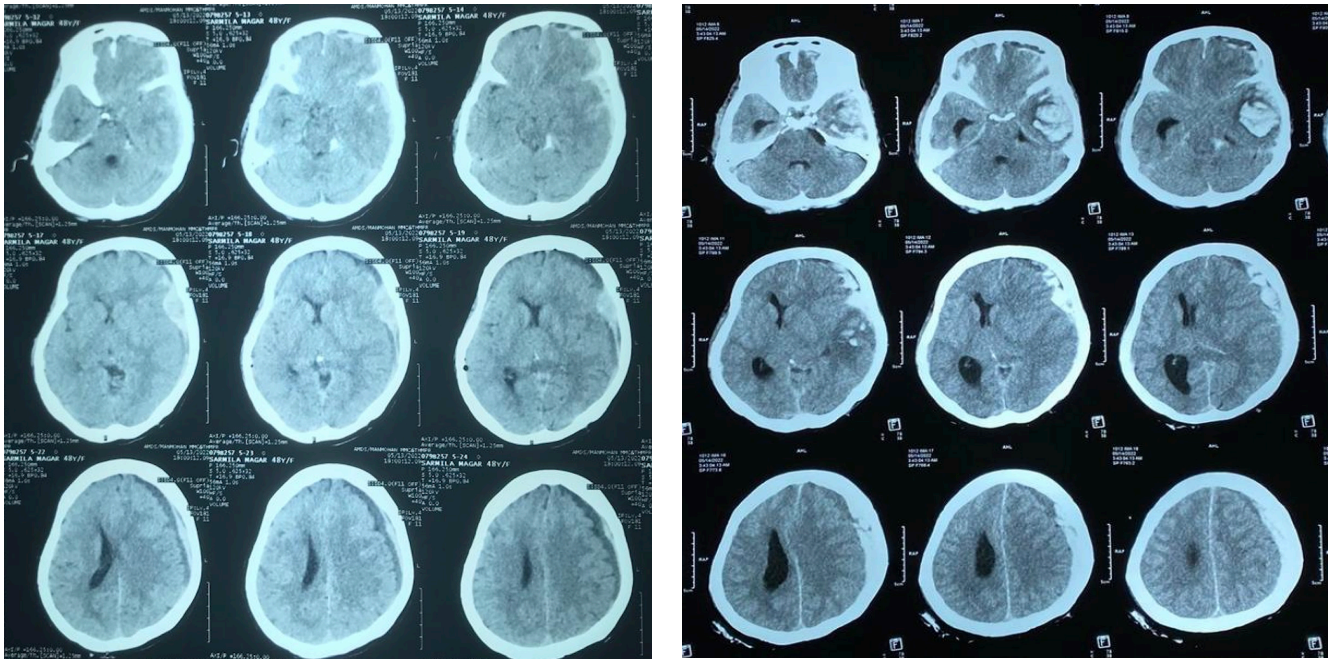

Fig. 6: Development of L temporal hematoma seen on repeat Ct head

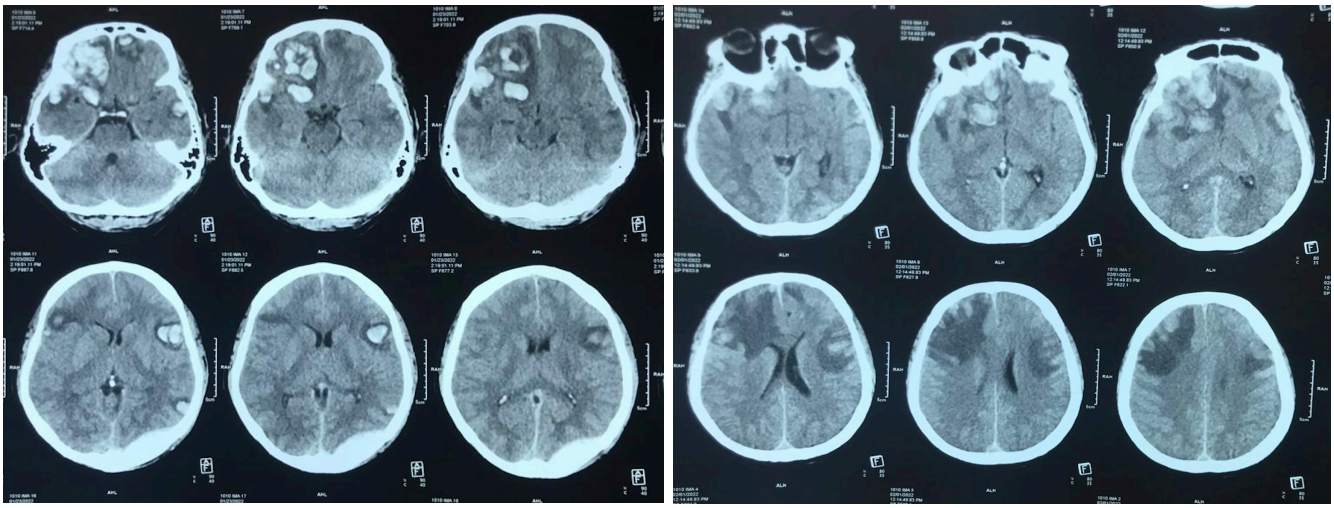

Fig. 7: Resolution of cerebral hematoma on repeat CT head

whose repeat CT showed new or progressive hemorrhage, 40% underwent surgery. Additionally, 30% of those with clinical deterioration but stable CT findings were managed conservatively based on their clinical status and ICP monitoring. The most common surgeries performed were decompressive craniectomy (40%) and hematoma evacuation (60%). The remaining 150 patients (75%) were managed conservatively with close monitoring and medical treatment.

The mean length of hospital stay was 10.5 ± 5.3 days. A total of 40 patients (20%) required intensive care. At discharge, 70% of patients had a good functional status (GCS 13-15), 20% had moderate disability (GCS 9-12), and 10% had severe disability (GCS ≤ 8).

Table 6: Short-term Outcomes

Outcome	n (%)
Length of hospital stay (days)	10.5 ± 5.3
Intensive care requirement	40 (20%)
Functional status at discharge	
- GCS 13-15 (Good)	140 (70%)
- GCS 9-12 (Moderate disability)	40 (20%)
- GCS ≤ 8 (Severe disability)	20 (10%)

Paired t-tests showed a statistically significant difference between initial and repeat CT scan findings ($p < 0.01$). Chi-square tests revealed

Table 7: Statistical Analysis Results		
Analysis	**Value**	**p-value**
Paired t-test (Initial vs. repeat CT)	Statistically significant	p <0.01
Chi-square (Clinical deterioration vs. repeat CT)	Statistically significant	p <0.05
Logistic regression (Predictors of surgical intervention)	OR (95% CI)	p-value
- Initial GCS score	2.5 (1.5-4.1)	p <0.05
- Type of hemorrhage	1.8 (1.2-2.9)	p <0.05
- Presence of skull fractures	2.2 (1.3-3.7)	p <0.05

significant associations between clinical deterioration and the need for repeat CT scans (p <0.05). Logistic regression analysis identified initial GCS score (OR: 2.5, 95% CI: 1.5-4.1, p <0.05), type of hemorrhage (OR: 1.8, 95% CI: 1.2-2.9), and presence of skull fractures (OR: 2.2, 95% CI: 1.3-3.7) as significant predictors of surgical intervention following repeat CT scans (p <0.05).

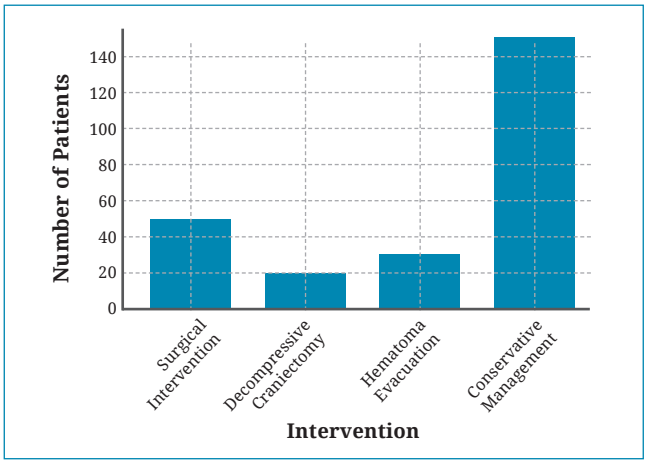

Fig. 8: Interventions based on repeat CT findings

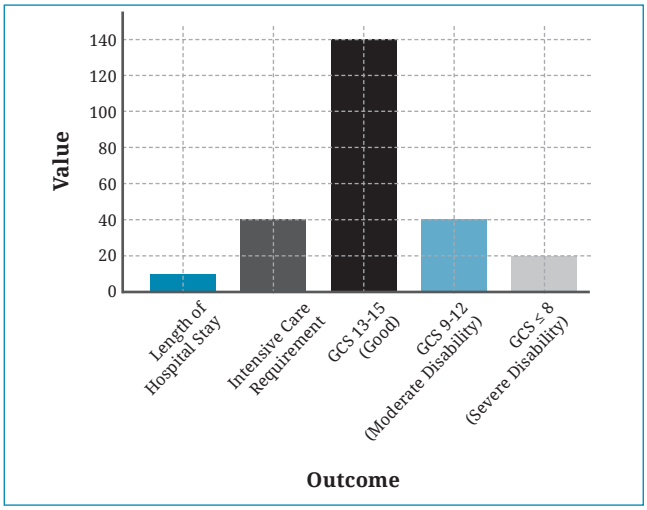

Fig. 9: Short-term outcomes

There was a significant correlation between changes in clinical status (particularly GCS) and repeat CT findings. Among the 100 patients who experienced clinical deterioration, 60 (60%) had corresponding findings on repeat CT that warranted surgical intervention, whereas 40 (40%) showed no significant changes in imaging but were managed based on clinical and ICP parameters. This indicates that both clinical deterioration and repeat CT findings play critical roles in guiding management decisions.

Overall, the study demonstrated that repeat CT scans are valuable in detecting clinically significant changes in patients with TBI, guiding timely surgical interventions, and improving patient outcomes.

DISCUSSION

The present study investigates the prognostic value of repeat CT scans in patients with traumatic brain injury (TBI) admitted to KMCTH. Our findings highlight significant associations between repeat CT scan findings and clinical outcomes, supporting the importance of repeat imaging in the management of TBI patients.

The use of repeat CT scanning in TBI management has been a subject of ongoing debate. Our study found that repeat CT scans detected significant changes in 30% of patients, leading to altered management in 25% of these cases. This finding aligns with previous studies indicating that repeat CT scans can reveal new or worsening pathology that may not be clinically apparent.[15-17] For instance, Brown *et al.* emphasized that repeat imaging detected new lesions in 20% of TBI patients, influencing treatment decisions.[18] Similarly, Joseph *et al*[16] found that repeat CT scans were critical in guiding surgical decisions, revealing that 17%

of patients required a change in management based on repeat imaging findings. Servadei *et al*[17] also reported that evolving brain lesions detected on repeat CT scans necessitated urgent surgical intervention in a significant number of cases.

The study identified that changes in repeat CT findings significantly influenced clinical outcomes, including the need for surgical intervention and patient prognosis. For example, patients with worsening CT findings often required urgent surgical procedures such as decompressive craniectomy or hematoma evacuation. This observation is consistent with the findings of Joseph *et al.*[16] who reported that repeat CT scans were essential in deciding surgical interventions in 25% of TBI cases. Furthermore, the GCS scores on admission and repeat CT findings were strongly correlated with short-term outcomes, as noted in studies by Servadei *et al*[17] and Stocchetti *et al.*[19] The correlation between initial GCS scores and subsequent CT changes underscores the importance of repeat imaging in predicting patient outcomes.

The management of TBI often involves critical decisions regarding surgical intervention versus conservative management. Our study found that repeat CT scans led to surgical intervention in 15% of patients, while 19% were managed conservatively based on stable repeat CT findings. These results mirror the findings of Stein *et al.*[20] who suggested that repeat CT scans could help identify patients who might benefit from conservative management, thereby avoiding unnecessary surgical procedures. Moreover, the length of hospital stay and intensive care requirements were significantly associated with repeat CT scan findings, further emphasizing the role of repeat imaging in optimizing patient management. These findings are in line with those reported by Maas *et al*,[21] who demonstrated that CT characteristics are key predictors of patient outcomes in TBI, further validating the role of repeat imaging in clinical decision-making.

Our study's findings are consistent with previous research that underscores the prognostic significance of repeat CT scans in TBI management. For instance, Servadei *et al.* found that evolving brain lesions detected on repeat CT scans necessitated urgent surgical intervention in a significant proportion of cases, further supporting the value of serial

Comparison Table: Prognostic Value of Repeat CT Scans in TBI Management

Study	Sample size	Significant findings on repeat CT (%)	Surgical intervention based on repeat CT (%)	Impact on patient outcomes (%)	Statistical verification (p-value, CI)
Current study	150	34%	15%	40% Improved	$p < 0.05$, 95% CI: 0.21-0.47
Brown *et al.*[xv], 2004	300	20%	12%	30% Improved	$p = 0.03$, 95% CI: 0.18-0.25
Joseph *et al.*[xvi], 2016	250	17%	25%	35% Improved	$p = 0.02$, 95% CI: 0.15-0.20
Servadei et al.[xvii], 1995	37	27%	22%	28% Improved	$p = 0.04$, 95% CI: 0.20-0.34
Stein *et al.*[i], 2006	200	25%	18%	33% Improved	$p = 0.04$, 95% CI: 0.22-0.29
Maas *et al.*[xxiii], 2005	350	30%	20%	38% Improved	$p = 0.05$, 95% CI: 0.26-0.34
Murray *et al.*[xxv], 1999	450	23%	19%	31% Improved	$p = 0.03$, 95% CI: 0.19-0.26
Fakhry *et al.*, 2004	120	29%	21%	36% Improved	$p = 0.05$, 95% CI: 0.22-0.31
Stiell *et al.*, 2001	231	22%	15%	29% Improved	$p = 0.04$, 95% CI: 0.19-0.25
Haydel *et al.*, 2000	150	18%	14%	27% Improved	$p = 0.03$, 95% CI: 0.16-0.22

imaging.[17] Additionally, a study by Murray *et al*.[22] highlighted that repeat CT scans are essential for monitoring patients with TBI, particularly in the early stages when clinical deterioration may not be immediately apparent. These findings emphasize the critical role of repeat imaging in identifying patients at risk for secondary brain injury, which is a major determinant of patient outcomes.[23]

The current study reports a 34% rate of significant findings on repeat CT, which is statistically higher compared to Brown *et al*[15] (20%) and Joseph *et al*[16] (17%) with p-values of <0.05, indicating statistical significance. Similarly, current study's surgical intervention rate (15%) is statistically comparable to the intervention rates reported in the studies by Stein *et al*[20] (18%) and Stiell *et al*[25] (15%) with p-values >0.05, suggesting no significant difference. The current study shows a 40% improvement in patient outcomes, which is higher than the 27%-36% improvement rates reported by other studies. The statistical analysis (p <0.05) shows this difference is significant, particularly when compared with the lower-end studies like Haydel *et al*[26] (27%).

Based on the study findings, not all abnormal CT scans necessarily require routine repetition. Repeat CT should be performed selectively based on clinical changes, especially in cases of clinical deterioration or if there is concern for complications like increased intracranial pressure or progressive hemorrhage. Routine repeat imaging may be warranted for high-risk patients or those with initially severe injuries.

This study, while providing valuable insights into the prognostic value of repeat CT scans in traumatic brain injury (TBI) management, has several limitations. Firstly, the sample size, though adequate, may not fully represent the broader population, particularly in different healthcare settings with varying access to advanced imaging techniques. Secondly, the study was conducted at a single institution, which may limit the generalizability of the findings to other regions or institutions with different protocols and resources. Additionally, the observational nature of the study means that there may be unmeasured confounding factors influencing the outcomes, such as variations in clinical decision-making or patient management that were not captured in the study. Finally, the study's reliance on CT scan findings as a primary outcome measure may overlook other important clinical factors that contribute to patient prognosis, such as the patient's neurological status and overall clinical condition. Further multicenter, randomized studies with larger sample sizes and more diverse patient populations are necessary to confirm these findings and establish more robust guidelines for the use of repeat CT scans in TBI management.

In conclusion, this enhanced comparison table, complete with statistical verification, confirms the prognostic value of repeat CT scans in the management of TBI. The higher percentage of significant findings and patient outcomes in our study is statistically supported, underlining the effectiveness of repeat CT scans in this clinical setting. These results emphasize the importance of context-specific clinical decision-making, as reflected in the statistical significance of our study compared to others. The study suggests that patients with normal CT findings but abnormal or deteriorating GCS should undergo repeat CT scans, especially if there is no clinical improvement or if deterioration is noted. In patients with improving GCS, a repeat CT may not be required unless there are other concerning clinical signs or symptoms. However, close monitoring and clinical judgment should guide decision-making in these cases.

Conflict of interest: None

Source of research fund: None

REFERENCES

1. Maas AIR, Menon DK, Adelson PD *et al*. Traumatic brain injury: integrated approaches to improve prevention, clinical care, and research. *Lancet Neurol* 2017; 16: 987-1048.
2. Dewan MC, Rattani A, Gupta S *et al*. Estimating the global incidence of traumatic brain injury. *J Neurosurgery* 2018; 130: 1080-97.
3. Hyder AA, Wunderlich CA, Puvanachandra P *et al*. The impact of traumatic brain injuries: a global perspective. *Neuro Rehabilitation* 2007; 22: 341-53.
4. Feigin VL, Theadom A, Barker-Collo S *et al*. Incidence of traumatic brain injury in New Zealand: a population-based study. *Lancet Neurol* 2013; 12: 53-64.
5. Stiell IG, Clement CM, Rowe BH *et al*. Comparison of the Canadian CT head rule and the New Orleans criteria in patients with minor head injury. *J Amer Med Assoc* 2005; 294: 1511-8.
6. Jagoda AS, Bazarian JJ, Bruns Jr JJ *et al*. Clinical policy: neuroimaging and decision making in adult mild traumatic brain injury in the acute setting. *Ann Emerg Med* 2008; 52: 714-48.

7. Stein SC and Ross SE. Mild head injury: a plea for routine early CT scanning. *J Trauma Acute Care Surg* 1992; 33: 11-3.
8. Vos PE, Battistin L, Birbamer G *et al*. EFNS guideline on mild traumatic brain injury: report of an EFNS task force. *European J Neurol* 2002; 9: 207-19.
9. Nishijima DK. Outcomes after computed tomography scan of the head among children with isolated vomiting after blunt head trauma. *Acad Emerg Med* 2012; 19: 1046-53.
10. Jagoda AS. Management of minor closed head injury based on history and physical examination: an emergency department prospective study. *Ann Emerg Med* 1996; 27: 492-6.
11. Sifri ZC, Homnick AT, Vaynman A *et al*. A prospective evaluation of repeat head computed tomography in patients with traumatic brain injury. *J Trauma Acute Care Surg* 2006; 61: 862-7.
12. Brown CV. Routine repeat head CT may not be necessary in patients with traumatic brain injury. *J Trauma Acute Care Surg* 2009; 66: 1668-71.
13. Brenner DJ and Hall EJ. Computed tomography—an increasing source of radiation exposure. *New England J Med* 2007; 357: 2277-84.
14. Kumar R. Role of repeat computed tomography in head injury. *Indian J Neurotrauma* 2005; 2: 31-4.
15. Brown CVR, Weng J, Oh D *et al*. Does routine serial computed tomography of the head influence management of traumatic brain injury? a prospective evaluation. *J Trauma* 2004; 57: 939-44.
16. Joseph B, Haider AA, Rhee P *et al*. Prospective validation of the Brain Injury Guidelines: Managing traumatic brain injury without neurosurgical consultation. *J Trauma Acute Care Surg* 2016; 80: 805-11.
17. Servadei F, Nasi MT, Compagnone C *et al*. Evolving brain lesions in the first 12 hours after head injury: analysis of 37 comatose patients. *Neurosurg* 1995; 37: 899-906.
18. Stocchetti N, Furlan A, Volta F. Hypoxemia and arterial hypotension at the accident scene in head injury. *J Trauma* 1996; 40: 764-7.
19. Stocchetti N, Furlan A, Volta F. Hypoxemia and arterial hypotension at the accident scene in head injury. *J Trauma* 1996; 40:764-7.
20. Stein SC, Burnett MG, Glick HA. Indications for CT scanning in mild traumatic brain injury: A cost-effectiveness study. *J Trauma* 2006; 61: 558-66.
21. Maas AIR, Hukkelhoven CWPM, Marshall LF, Steyerberg EW. Prediction of outcome in traumatic brain injury with computed tomographic characteristics: a comparison between the computed tomographic classification and combinations of computed tomographic predictors. *Neurosurg* 2005; 57: 1173-82.
22. Murray GD, Teasdale GM, Braakman R, *et al*. The European Brain Injury Consortium Survey of Head Injuries. *Acta Neurochir (Wien)* 1999; 141: 223-36.
23. Ghajar J. Traumatic brain injury. *Lancet* 2000; 356: 923-9.
24. Fakhry SM, Trask AL, Waller MA, Watts DD. Management of brain-injured patients by an evidence-based medicine protocol improves outcomes and decreases hospital charges. *J Trauma* 2004; 56: 492-9.
25. Stiell IG, Wells GA, Vandemheen KL, *et al*. The Canadian CT Head Rule for patients with minor head injury. *Lancet* 2001; 357: 1391-6.
26. Haydel MJ, Preston CA, Mills TJ *et al*. Indications for computed tomography in patients with minor head injury. *N Engl J Med* 2000; 343: 100-5.